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Process flow to integrate nanostructures on silicon grass in surface micromachined systems

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Abstract. The process flow to integrate metallic nanostructures in surface micromachining processes is presented. The nanostructures are generated by evaporation of microstructured silicon grass with metal. The process flow is based on the lift-off of a thin amorphous silicon layer deposited using a CVD process. All steps feature a low temperature load beneath 120 °C and high compatibility with many materials as only well-established chemicals are used. As a result metallic nanostructures usable for optical applications can be generated as part of multi-layered microsystems fabricated in surface micromachining.

1. Introduction

Silicon grass as a non-periodical needle-like microstructure shows high potential for numerous applications, such as controlling wetting behaviour of surfaces or for chip assembly [1, 2]. The additional vapour deposition of metal results in nanostructured metallic needles on top of the microstructured silicon grass (see Fig. 1).

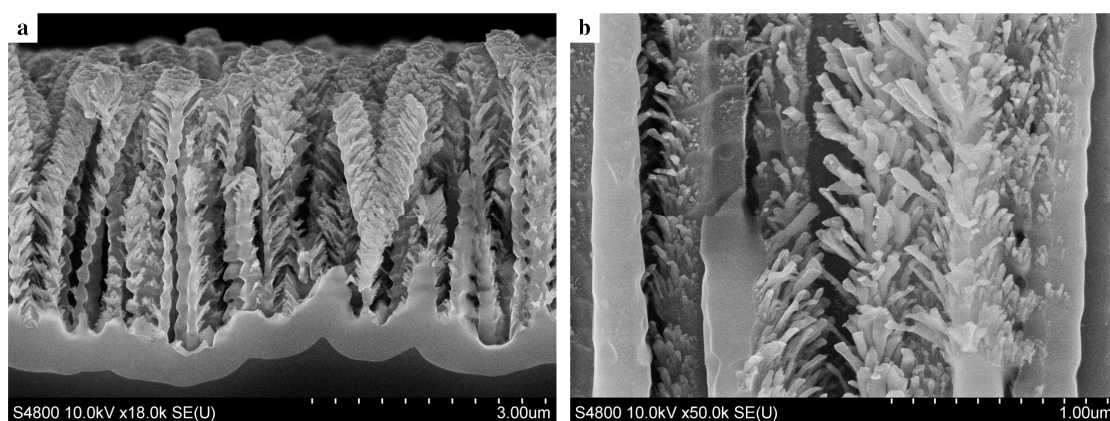


Figure 1. **a** SEM picture of silicon grass evaporated with metal; **b** SEM picture of the nanostructured needle-like metal grown on the sidewalls of silicon grass



These structures can be used for optical applications as for high emittance infrared sources or absorbers [3]. As described in [3], the silicon grass is typically etched into the bulk of a silicon wafer, which limits the position of the nanostructures in the microsystem and moreover restricts the fabrication flow. Here we present a process flow to generate silicon grass using surface micromachining processes only. The presented technology enables the integration of silicon grass with vapour deposited nanostructures at the point of interest and in an arbitrary position of a multi-layered microsystem; such as a free-standing membrane that features thermocouples and shall be used as a high efficient infrared absorber.

2. Fabrication Flow

The process flow starts on a thermally oxidized silicon wafer (Fig. 2 **a**). Subsequently, a patterned thick photoresist for the lift-off is lithographically generated (Fig. 2 **b**). An amorphous silicon layer with a thickness of about 5 μm is deposited using an ICP CVD process (Fig. 2 **c**). This step causes the maximum temperature load of about 120 $^{\circ}\text{C}$ for all process steps. Afterwards the microstructured silicon grass is etched into the thin amorphous silicon layer using a fluorine based dry-etch process. Here, the thermal SiO_2 layer is used as an etch stop layer. The self-masking mechanism which is crucial for the generation of silicon grass during the dry-etch process is extensively described in [4].

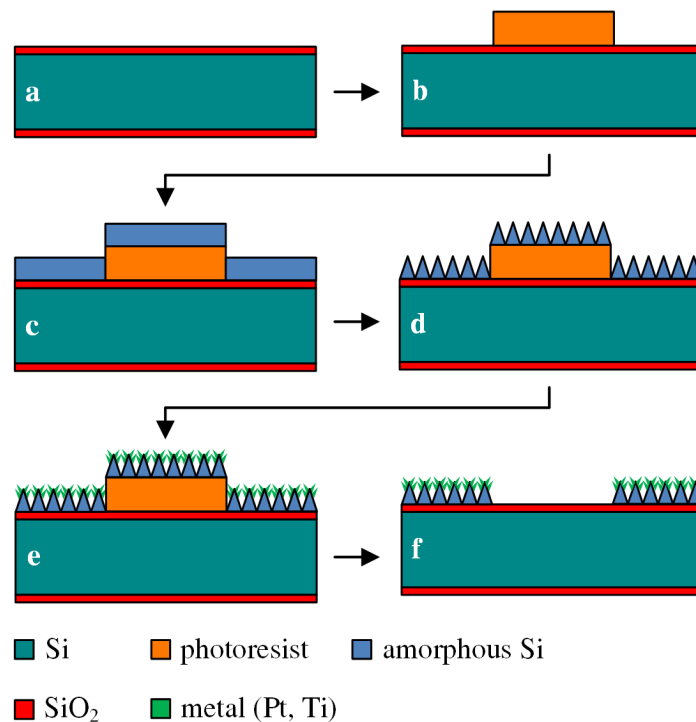


Figure 2. Process flow utilizing surface micromachining processes only, for integration of metallic nanostructures on top of silicon grass in surface MEMS

Afterwards, metal is vapour deposited on top of the silicon grass in order to form needle-like nanostructures (Fig. 2 **e**). In the last step the lift-off is realized utilizing a conventional remover product that is compatible with a lot of metallic, dielectric and semiconductive materials.

3. Process results

Dry-etching of silicon grass depends on the load. The lift-off process whereat the complete substrate is covered with an amorphous silicon layer causes a hundred percent load always. Therefore a stable process result that is independent of the current design is achieved. Process results after etching the silicon grass nearby the photoresist are shown in figure 3.

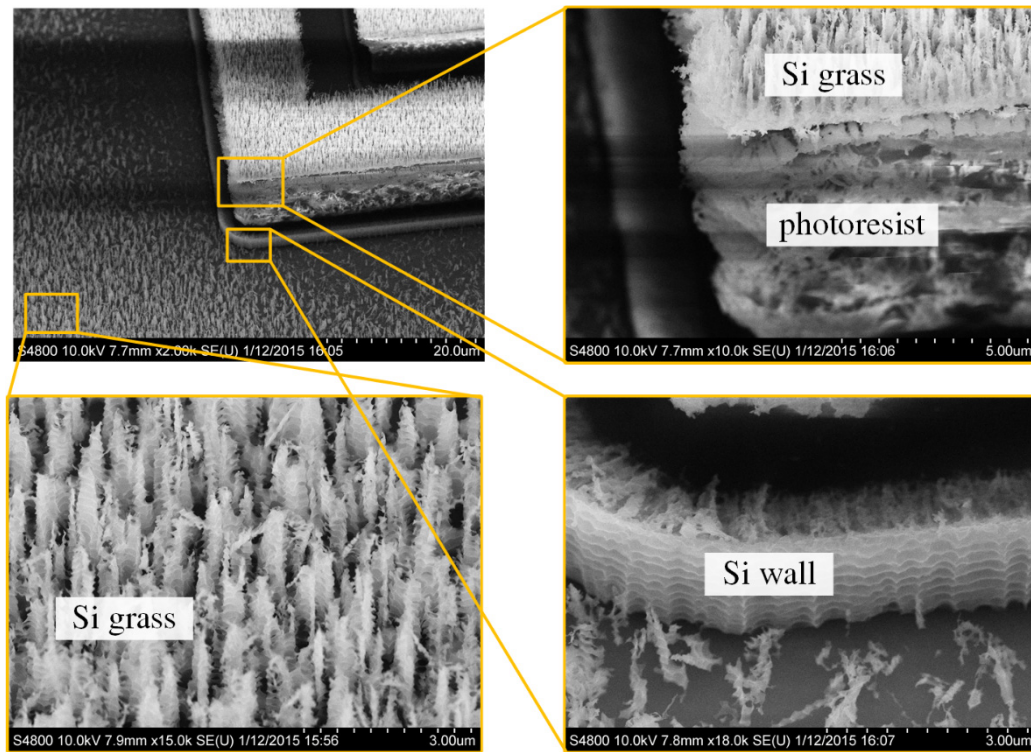


Figure 3. SEM pictures of silicon grass dry-etched in a thin amorphous silicon layer

Silicon grass is formed on top of the photoresist, too. In the close environment of the photoresist no silicon grass is generated. It is likely, that ion reflections at the photoresist sidewalls cause an enhanced passivation etching. Residual passivation clusters on the silicon are elsewhere responsible for the forming of silicon grass. Without these clusters, the silicon layer is removed completely. Directly aside the photoresist no etching occurs and a solid silicon wall is formed showing the typical etch ripples.

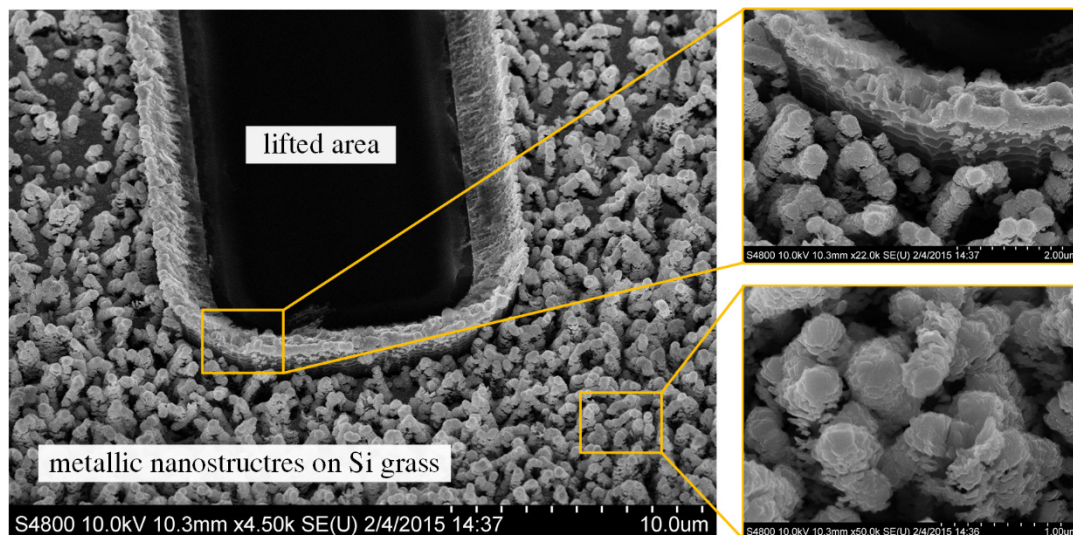


Figure 4. SEM pictures of the lift-off result for patterning silicon grass evaporated with metal

Figure 4 shows the process result after the lift-off process was executed. A typical non-periodic nanostructured surface is formed. The metal grows on top of the silicon grass as well as on the scallops of the etched silicon grass and forms fan-shaped crystalline nano-needles.

The developed process chain was used for integration a patterned silicon grass area evaporated with metal into a microsensor for detecting infrared radiation based on the Seebeck-effect (see Fig. 5). The structures are known to augment infrared absorption which therefore is expected to increase the sensitivity and efficiency of the microsensor.

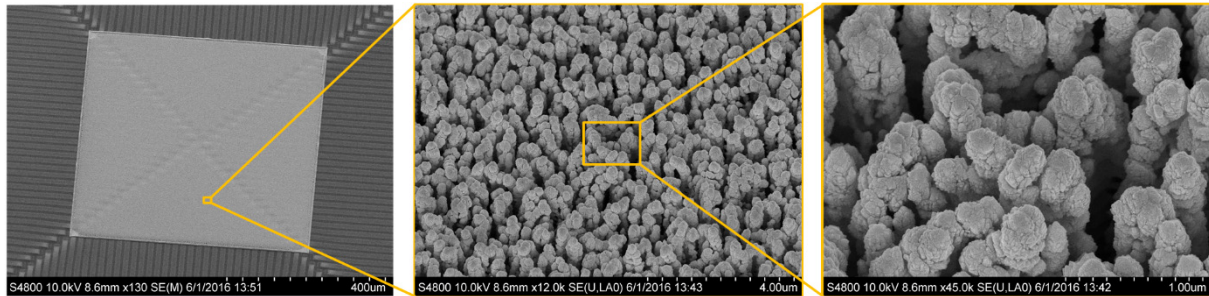


Figure 5. SEM pictures of a patterned infrared absorbing area consisting out of silicon grass evaporated with metal; the absorber area is integrated on a multi-layered microsensor for measuring infrared radiation using the Seebeck effect.

4. Conclusions

Silicon grass is generated by dry-etching a thin amorphous silicon layer that is deposited in a CVD process. Cascaded metallic nanostructures generated by vapour deposition on silicon grass can be fabricated at the point-of-interest by using surface micromachining processes only. The presented process flow exhibits a very low temperature load ($<120^{\circ}\text{C}$) so that the integration of such structures in temperature-sensitive systems is possible, e.g. on thermally stable polymers.

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